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On concrete restrained eccentric ring and squared eccentric ring shrinkage test methods

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HIGHLIGHTS

- Two improvements based on concrete restrained shrinkage ring test.
- The inner ring in mold geometry is now placed eccentrically.
- Stress concentration is induced by the eccentricity in mold geometry.
- Cracking location is predictable.
- Cracking time is noticeably shortened.

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ABSTRACT

In the conventional restrained ring test method (RRTM) for evaluating restrained concrete shrinkage, the specimen geometry is a concentric ring, which causes cracking initiation anywhere in the ring randomly and it is inconvenient to observe. Aiming at improving the identification of cracking location, this article presents two improvements based on RRTM, namely the restrained eccentric ring test method (RERTM) and the restrained squared eccentric ring test method (RSERTM), in which the specimen geometry is a non-concentric ring for the former and a square with a non-concentric hole inside for the latter. In other words, in comparison with RRTM, the specimen geometry in RERTM and RSERTM now is featured with the inner ring being placed eccentrically. Numerical simulation was performed to guide the selection of specimen dimensions and to reveal the stress concentration phenomenon. Experiments were conducted to record cracking time and cracking locations. It is seen that, compared with RRTM, the eccentricity introduced in RERTM and RSERTM will give rise to stress concentration, guide cracking location, and noticeably shorten cracking time.

1. Introduction

Early-stage shrinkage is an inherent attribute of concrete. When restrained shrinkage takes place, cracks may appear. These cracks, though tiny in the beginning, reduce the concrete durability and may pose a serious problem for the integrity of the whole concrete structure. Therefore, understanding concrete shrinkage phenomenon is an important subject. There are a number of test methods developed to measure the early shrinkage of concrete. Among these methods, the restrained ring test method (henceforth referred as RRTM) introduced by Carlson and Reading [1], is widely referred. Wiegrink, Marikunte and Shah employed RRTM to evaluate shrinkage cracking of high-strength concrete [2]. The same ring test method was employed by Briffaut et al. [3], but the ring material was brass and was heated to estimate the influence of reinforcement and construction joints on shrinkage cracks.

The principle of RRTM is brilliant, which exerts a rigid inner wall to against the inward deformation, so the combination of the geometry and restraint will induce the rise of tensile stress in specimen and initiate cracks when tensile stress exceeds specimen tensile strength. The conventional RRTM enjoys many merits that methodology is straightforward, test apparatus is simple, and specimen geometry is a circle and axially symmetric. At the same time, this leads to the situation that shrinkage cracks may appear

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randomly anywhere within 360° along the circumference of the ring, and measuring cracking time in specimen becomes a challenging task. With advanced sensors and measuring gadgets available nowadays, it appears that recording cracking time will be better facilitated if cracking location can be known, or anticipated within a certain segment in specimen.

In RRTM, the outer and/or top facades of the ring specimen are exposed to air after being de-molded. For the purpose of limiting cracking locations, Xie [4] tried to seal the ring facades partially by placing glues on them. In this way, little moisture was evaporated in this partially sealed ring segment, and this created different evaporation in a ring specimen, which is uniform in RRTM. The result was that cracking took place only in the segment that was not sealed. Li and co-workers [5] proposed an innovative method of elliptical ring for "promoting the crack propagation rate of mortar or concrete".

Crumb rubber is a soft material and it has been observed by a number of studies that adding rubber crumbs into cement based materials will slow cracking occurrence [6,7]. Turatsinze, Bonnet and Granju further found that adding rubber aggregate into cement mortar would improve cracking shrinkage resistance [8]. Furthermore, Wu [9] made the mortar ring specimens that consisted of two segments, one was made with plain mortar and the other was made with plain mortar and crumb rubber. This time, a single specimen was made of two materials and the material uniformity was broken. The results showed that shrinkage cracking occurred only in the segment that was not mixed with crumb rubber.

After studying the idea of non-uniformity in moisture evaporation and the ring material, the geometry is the subsequent consideration. Hu [10] studied a mortar mold that had a shape of a square with: (1) a co-axial hole inside; and (2) with an axially eccentric hole inside. The same work was extended by Zhao [11], but this time, rubber crumbs were added into mortar. In a similar fashion, the case for lightweight concrete was studied by Wang [12]. The experiments reported in [10–12] were carried by using a plastic mold that did not have good rigidness and was easy to deform, and the specimens made by those molds were not in good quality. But the three studies serve to explore how the eccentricity will affect the cracking location, and the results do show that this eccentricity will guide cracking location in this unusual specimen configuration of mortar/lightweight concrete restrained shrinkage tests.

2. Aims

To continue this eccentricity study and following the principle of RRTM as stated in the beginning of this article, a systematic effort is made here to introduce two specimen geometries. The first one is a ring with its outer and inner circles being not co-axial, e.g. the ring is eccentric, and the corresponding test name is the restrained eccentric ring test method (henceforth referred as RERTM, see Fig. 1a). The second is a square with a hole inside but the hole is also eccentric, and the corresponding method is named as, in some awkwardness, the restrained squared eccentric ring test method (henceforth referred as RSERTM, see Fig. 1b). Though RSERTM can be hardly called a ring but "the ring" is kept to honor RRTM. Based on Fig. 1a and b, an eccentric index, e, can be defined as:

$$e = \text{distance between Point-A and Point-B}/\text{distance between Point-C and Point-D} \quad (1)$$

It can be seen that when $e = 1$, the eccentricity disappears, and RERTM returns to RRTM, and RSERTM returns to the configuration of a square with a co-axial hole inside. When e is less than 1, the eccentricity arises.

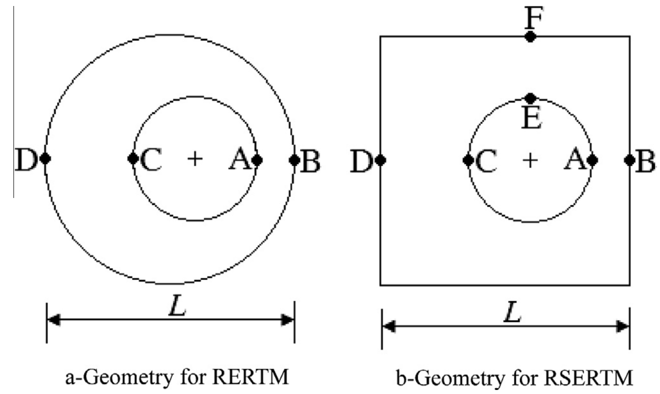

Fig. 1. (a) Geometry for RERTM. (b) Geometry for RSERTM.

3. Determining the geometry and size of specimen molds

For both RERTM and RSERTM, the first task is to design the specimen molds. The material selected for the molds is a low carbon steel plate with Young's modulus being 200 GPa and yield strength being 310 MPa, which is considered a common grade steel and is widely available and used in China. The molds are assembled by those steel plates that have a thickness of 3 mm, and only the thickness for the inner ring is 20 mm for the purpose of achieving a rigid restraint against concrete shrinkage.

As for the size dimension, there are many reported studies on RRTM, and a portion of them is collected in Table 1. It can be seen from Table 1 that taking 300 mm to be the diameter for the inner ring is a common selection, and so is the case in this article. Here, 300 mm represents the diameter of the outer boundary of the inner ring, and the thickness of the inner ring is 20 mm.

Since the molds are designed for concrete material in this article, taking 25 mm as the maximum aggregate size is more representative than 10 mm. Subsequently, the specimen width is taken as 75 mm to assure it is three times as big as the maximum aggregate size. For RERTM and RSERTM, this means that the narrowest width is 75 mm, or the distance between Point-A and Point-B as depicted in both Fig. 1a and b is 75 mm. In order to design a squared transverse cross-section of the specimen, the height is chosen to be 75 mm, which also assures that the height is 3 times as big as the maximum aggregate size.

The three parameters of mold configuration are now chosen that the diameter of the inner ring is being 300 mm, the narrowest width is 75 mm and the height is 75 mm. For RRTM, those three parameters fully specify the mold geometry and size, which is a concentric ring with the inner ring being 300 mm, the outer ring being 450 mm and the height being 75 mm. But for RERTM and RSERTM, one more parameter, L, needs to be specified, which represents the diameter for the outer ring for RERTM in Fig. 1a and the length of the side of the square for RSERTM in Fig. 1b. However, how to determine L is an open question and in the next section, the FEM simulation is conducted to provide guidance for selecting L, which now is related to e defined in Eq. (1) by:

Table 1
Ring dimension and size of reported studies (mm).

Author name(s)	Inner radius	Height	Width
Subramaniam et al. [13]	305	140	35
Lomboy and Wang [14]	330	152	38
Li et al. [15]	305	140	35
Dong et al. [16]	330	75	38
Turcry et al. [17]	220	70	70
Briffaut et al. [4]	480	70	70
Hossain and Weiss [18]	300	75	75